UNIVERSITY OF OTTAWA

FACULTY OF ENGINEERING

The FLAB Mat:

User and Product Manual

GNG1103 – Engineering Design

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TEAM 2

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TABLE 1 - ACRONYMS

Acronym	Definition
2D	Two Dimensional
3D	Three Dimensional
EPDM	Ethylene Propylene Diene Monomer
FLAB	Fiorelli Leo Aliyaah Ben
HS	Heated sidewalk
UPM	User and Product Manual

TABLE 2 - GLOSSARY

Term	Definition
5/M6	The size of the Allen key.
“Brick”	A term given to the combination of many small J-shaped pieces.
Connection Rods	Slide through the “bricks” and tie them together.
“Fio and the Zoomers”	Team name for team 2 of GNG1103-F.
J-Shaped Piece	The main piece used in the modular sliding mechanism. Form “bricks” which slide into each other.
Lower interlock lip	The interlocking mechanism connected to the bottom of the mat.
Ramp/J-Shaped Piece	Specialized J-shaped piece which forms a ramp shaped “brick” that can slide into regular J-shaped “bricks”.
Self-regulating heating cable	A heating cable capable of regulating its heat output based on the surrounding temperature.
Top/Bottom Connection pieces	Connect the “bricks” to the rubber mat.
“Tongue”	The smallest portion of the J-shaped “brick” that loops back around
Type B	An electrical socket with 3 pins: 2 flat parallel pins and a round grounding pin.
Upper interlock lip	The interlocking mechanism connected to the top of the mat.

1 Introduction

The primary objective of this User and Product Manual (UPM) is to serve as a useful guide for the safe operation and use of the FLAB Mat for both maintenance personnel and pedestrians alike. In addition, the overall design and construction process of the final prototype is documented in this user manual to aid in the reproduction of the product and attempting further improvements.

This document first highlights the issues with current winter maintenance methods on-campus at the University of Ottawa. This is to provide a background on the necessity of the student group's designed solution. Through analysis of the initial request, the client's needs were identified and individually addressed in the FLAB Mat's proposed subsystems. General directions are then briefly provided for the initial set up of the mat prior to its installation and use to ensure optimal performance. Next, the user manual outlines detailed instructions for each subsystem included in the FLAB Mat. These directions also include figures for visual aides to ensure proper use of every feature of the mat. Moreover, troubleshooting information is given for the product in case of deviations from standard operation in addition to maintenance tips for extending the lifespan of the FLAB Mat.

Following this, comprehensive documentation of each FLAB Mat subsystem is presented which includes all construction materials and equipment, their respective material costs, and step-by-step instructions of the manufacturing process. Likewise, visual aides are provided when possible, in describing each subsystem's construction. Testing methods and relevant results are subsequently listed to demonstrate how the FLAB Mat's design was validated. Lastly, any conclusions and recommendations from the student team are provided in the final section directed for users looking to replicate the FLAB Mat design and look to improve on its existing features.

2 Overview

The University of Ottawa is looking for an alternative solution for winter maintenance. Rock salt is currently being used to melt ice and snow. However, the rock salt causes infrastructure and environmental damage which contributes to a high cost for winter maintenance. As a result, a modular heated sidewalk has been developed to provide a sustainable option for winter maintenance.

The client requires a heated sidewalk that is modular, safe, removable, storable, cost-effective, and easily integrated into the existing campus buildings. The FLAB Mat effectively satisfies all these conditions, with additional emphasis on simplicity, ease-of-use, and environmental sustainability.

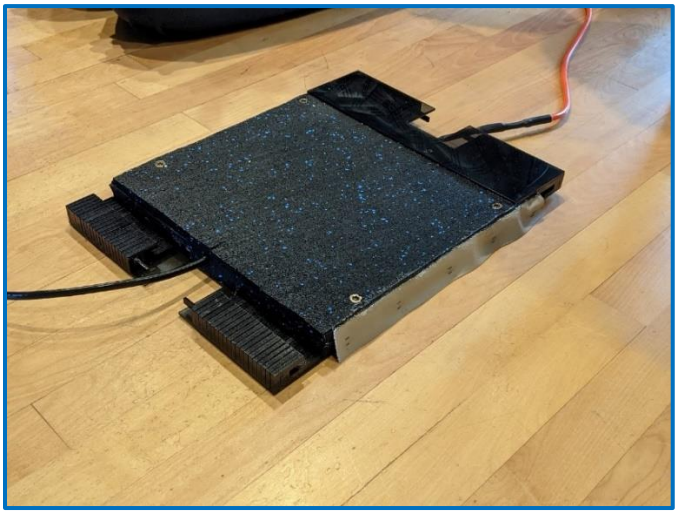


FIGURE 1 - THE FLAB MAT OVERVIEW

The FLAB Mat features an interlocking mechanism that connects each modular section together. This mechanism also applies to the end piece where an accessibility ramp connects. The rubber surface provides durability, water resistance to protect the heating cable, and sufficient traction for users to walk on. The flaps, zippers, and snap fasteners on each side allows easy access to the heating cable for repair. The grommets secure the top and bottom layer of the rubber mat and guide the concrete screws during installation. Lastly, the heating cable successfully heats up the rubber surface to melt ice and snow during winter. This system will operate when the temperature probe detects temperature conditions below 37°F.

2.1 Cautions & Warnings

Users are recommended to read this section before the installation process to prevent injuries and possible damage to the product.

1. The zippers must be gently unzipped.
2. Do not place the mat near extreme heat or fire sources.
3. Do not plug in the cable with wet hands.
4. The temperature probe must be immersed at a minimum temperature at 37°F to begin heating.
5. Do not eat the mat.
6. Keep away from children.

3 Getting Started

Thank you for choosing the FLAB Mat! Before using this product, it is important to be familiarized with its many features and uses. This section provides a general walkthrough of how to use the modular heated mat, as well as its external components.

3.1 Set-up Considerations

Below, a simplified diagram of the product is illustrated to provide a visual depiction of each of the features that will be referred to in this document.

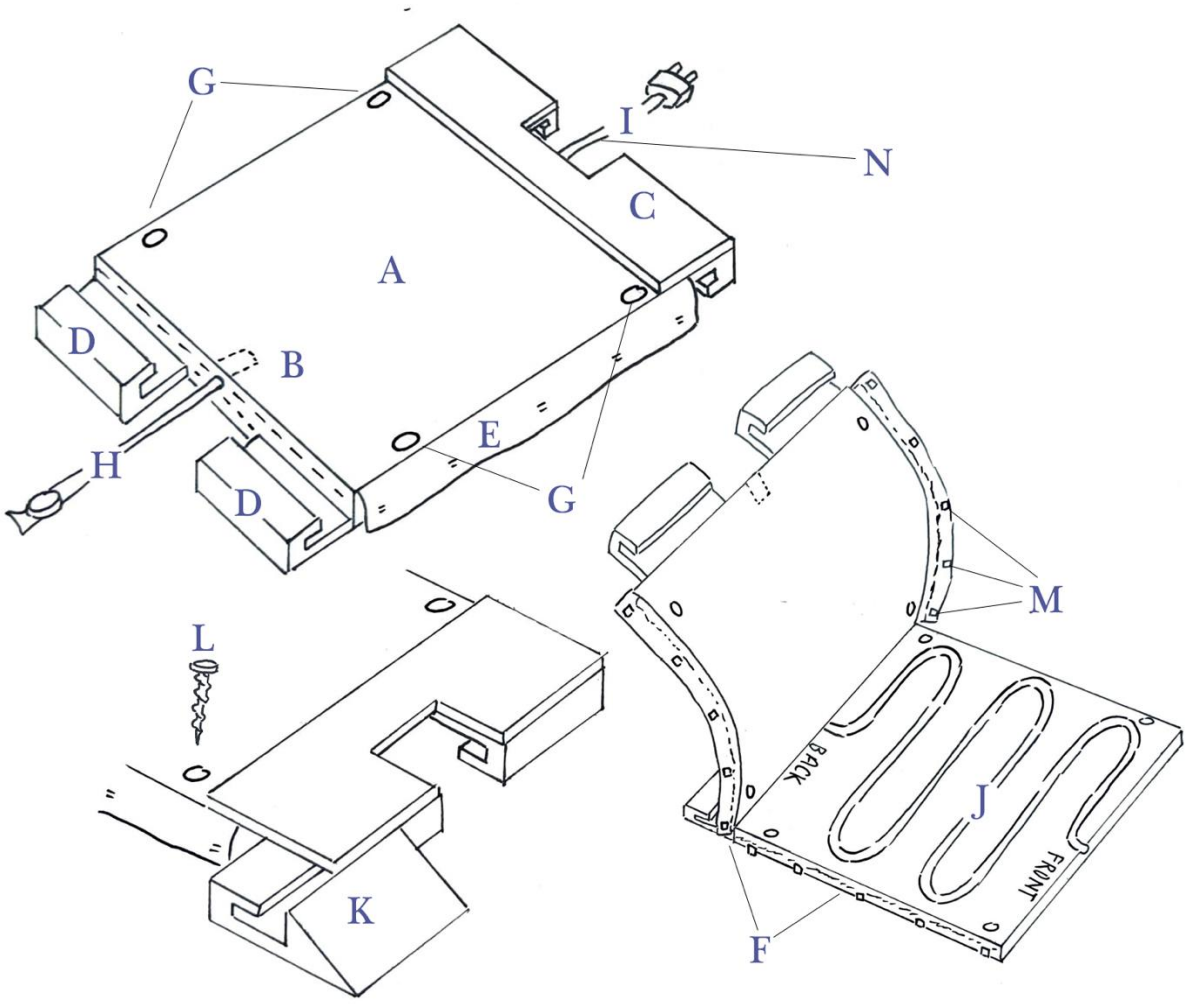


FIGURE 2 - SIMPLIFIED DIAGRAM OF FLAB MAT

TABLE 3 - OVERVIEW LEGEND

A: Rubber body	**E:** Side flap	**I:** Plug	**M:** Snap fasteners
B: Notch	**F:** Side zipper	**J:** Cable channel	**N:** Heating cable
C: Upper interlocking lip	**G:** Grommets	**K:** Accessibility ramp	
D: Lower interlocking lip	**H:** Temperature probe	**L:** Concrete screw	

3.1.1. Rubber Body

This is the main rubber body of the modular heated sidewalk. It is comprised of 3 layers of EPDM rubber: a bottom insulating layer, a middle layer containing the embedded heating cable, and a top layer for pedestrians to walk on.

3.1.2. Notch

The notch is comprised of two small slits cut into the middle-back edge of the rubber body. It exists as an aid to ensure that the external temperature probe does not obstruct the interlocking mechanism when connecting the mat to adjacent mats.

3.1.3. Upper Interlock Lip & Lower Interlock Lip

The upper and lower interlocking lips of the mat are the main mechanisms involved in the mat's modularity. Collectively, both the upper and lower lips are also referred to as the interlocking mechanism. The upper interlocking lip is located along the front edge of the mat and is exclusively attached to the top layer of the rubber body. The lower interlocking lip is located along the back edge of the mat and is exclusively attached to the bottom two layers of the rubber body. These components are what allow for a secure connection between multiple adjacent mats.

3.1.4. Side Flaps, Side Zippers, & Snap Fasteners

The side flaps, side zippers, and snap fasteners collectively make up the repairability mechanisms that are located on both the left and right edges of the mat. The side flap is the most external component of this mechanism and exists to protect the inner electrical components of the mat from melted snow leakage and water damage. The side zipper is located underneath the side flap and allows the user to access to the mat's inner components for maintenance and repairability. The snap fasteners exist between the side flaps and side zippers to ensure connection between the two components.

3.1.5. Grommets

The grommets are located at each of the four corners of the mat and allow the mat to be securely connected to sidewalks, entryways, and other high-traffic pedestrian paths. Each grommet is positioned inside a small hole in the rubber body to protect the holes from wear and damage. The grommets are also removable and can be removed using a Size 5/M6 Allen Key. They are most compatible with the screw dimensions detailed below.

3.1.6. Heating Cable, Temperature Probe, & Plug

The heating cable is the main contributor to the heating element of the FLAB Mat. It runs through the middle layer of the rubber body and protrudes externally on both the front and back ends of the mat. The front protruding part of the cable contains the electrical plug that is compatible with a Type B (3-pin/grounded) electrical socket. The back protruding part of the cable contains the temperature probe that is the main component for activating the heating cable.

3.1.7. Cable Channel

The cable channel is located within the middle layer of the rubber body and provides a location for the heating cable to be embedded within. This layer also has the "FRONT" and "BACK" ends visibly labelled on it to help users navigate the FLAB Mat.

3.1.8. Accessibility Ramp

The accessibility ramp is an external component of the mat designed to allow ease of access to wheelchair users, strollers, and other such users of the FLAB Mat. It should be connected to the frontmost/backmost edge of the mat(s) in the same fashion as the main interlocking mechanism.

3.1.9. Concrete Screws

The concrete screws are an external tool that can be used to help secure the mat to the ground for added stability. It is recommended to use concrete-specific screws with a diameter of 3/16'' and a length of 3¼''. Shorter or longer screws may also be used depending on specific needs or restrictions.

3.2 User Access Considerations

Accessing the FLAB Mat and each of its several components is an entirely physical process; unlike its competitors, the FLAB Mat does not contain any digital or electronic components. Having said this, it is still important to highlight which components of the system should be accessible to which groups of users of the mat.

3.2.1. Maintenance & Set-up Personnel

This section is intended for individuals who will be involved with the set-up or maintenance of the FLAB Mat.

These users should have full access to and knowledge of every component in the system. This includes the mat's modularity, repairability, heating, stability, and storage subsystems. The operation of each of these individual subsystems is further detailed in Section 4. Users involved in the set-up of the mat should be especially familiar with the modularity, heating, stability, and storage subsystems. Users involved in the maintenance of the mat should be especially familiar with the repairability subsystem.

3.2.2. Pedestrians

This section is intended for general pedestrian usage. For additional pedestrian accommodations, please refer to Section 3.2.3.

Pedestrians are intended to only be able to access the mat for walking purposes; that is, pedestrians can walk on any part of the modular sidewalk from any point at which it is stationed. Due to the combination of the stability and modularity subsystems, pedestrians and members of the public will not (and should not) have access to any other components of the mat.

3.2.3. Pedestrians with Accessibility Requirements

This section is intended for accommodative pedestrian usage. This specifically includes (but is not limited to): pedestrians using wheelchairs, scooters, walkers, strollers, or any other individual presented with a small ground level difference obstacle.

This category of pedestrians has the same level of access to the mat's components as was discussed in Section 3.2.2. However, pedestrians that fall within this category are advised to access the modular sidewalk from the accessibility ramp located at either end of the length of adjacent mats.

3.3 Accessing the System

The following procedure must be executed to obtain full access to the FLAB Mat's capabilities.

1. If being placed in a new location, set-up personnel must pre-drill appropriately sized holes into the ground where the mat is anticipated to be placed. The dimensions of these holes should reflect the dimensions of concrete screws that will be used to secure the mat. The mat can be used as a guide for the precise location of the holes.
2. If using the FLAB Mat after repair, users must ensure that the mat is fully reconstructed as per the instructions highlighted in Section 4.2. This includes ensuring the heating cable is aligned in the cable channel following the directions indicated on the middle layer of the rubber body; the plug must be placed at the FRONT end and the temperature probe must be placed at the BACK end. Ensure that the zipper is closed, the flap is closed, and the grommets are screwed in.
3. If using multiple mats, the mats can now be connected modularly. Please refer to Section 4.1 for a detailed explanation of how to achieve this.
4. Align the mat(s) with the pre-drilled holes in the ground. Also ensure to align the front end of the mat closest to the power source that will be used. The mats should be positioned so that the holes in each of the grommets are aligned with the holes in the ground. The concrete screws can now be drilled in. This is further explained in Section 4.4.
5. Attach the accessibility ramp to the appropriate edge of the mat(s) via the process explained in Section 4.1.2.
6. Place the temperature probe in an ice bath or a sufficiently cold location for the heating cable to begin operating. The heating cable will activate at a temperature of 37°F/2.78°C or lower and will turn off if it has reached a temperature of 50°F/10°C.
7. Plug the heating cable into a Type B/grounded outlet. A detailed explanation of Steps 6 and 7 can be seen in Section 4.3.

The FLAB Mat is now ready to be used!

3.4 System Organization & Navigation

Once the steps detailed in Section 0 have been completed, the FLAB Mat can be successfully used to melt snow. After fulfilling the set-up criteria, no further action will need to be taken to achieve functionality of the mat.

If functioning correctly, the mat should successfully show a significant difference in snow buildup levels from anywhere between 20-90 minutes, depending on the volume of precipitation. The melted snow should then be seen flowing off the side of the mat due to the water-wicking abilities of the rubber surface. This process works best if the mat is placed on a surface with a natural incline. Sidewalks are best for this, since they are already designed to have a slight incline.

If the heating component does not appear to be functioning, or if any section of the mat appears to need maintenance of any kind, refer to Section 4.2 for repairability or Section 5 for troubleshooting and support.

3.5 Exiting the System

When finished using the FLAB Mat, the following steps should be followed to cease the mat's operations safely and successfully.

1. Remove the temperature probe from its ice bath/temperature-controlled environment.
2. Unplug the heating cable from the outlet.
3. Unscrew the concrete screws from the grommets.
4. Disconnect the modular sections of adjacent mats. The accessibility ramp can also be disconnected.

After completing these steps, the mat can now successfully be removed from the ground where it has been placed and stored for later use. It is highly recommended to store the mat(s) in a stacked fashion on a surface with little/no incline. See Section 4.5 for further insights on the storage process.

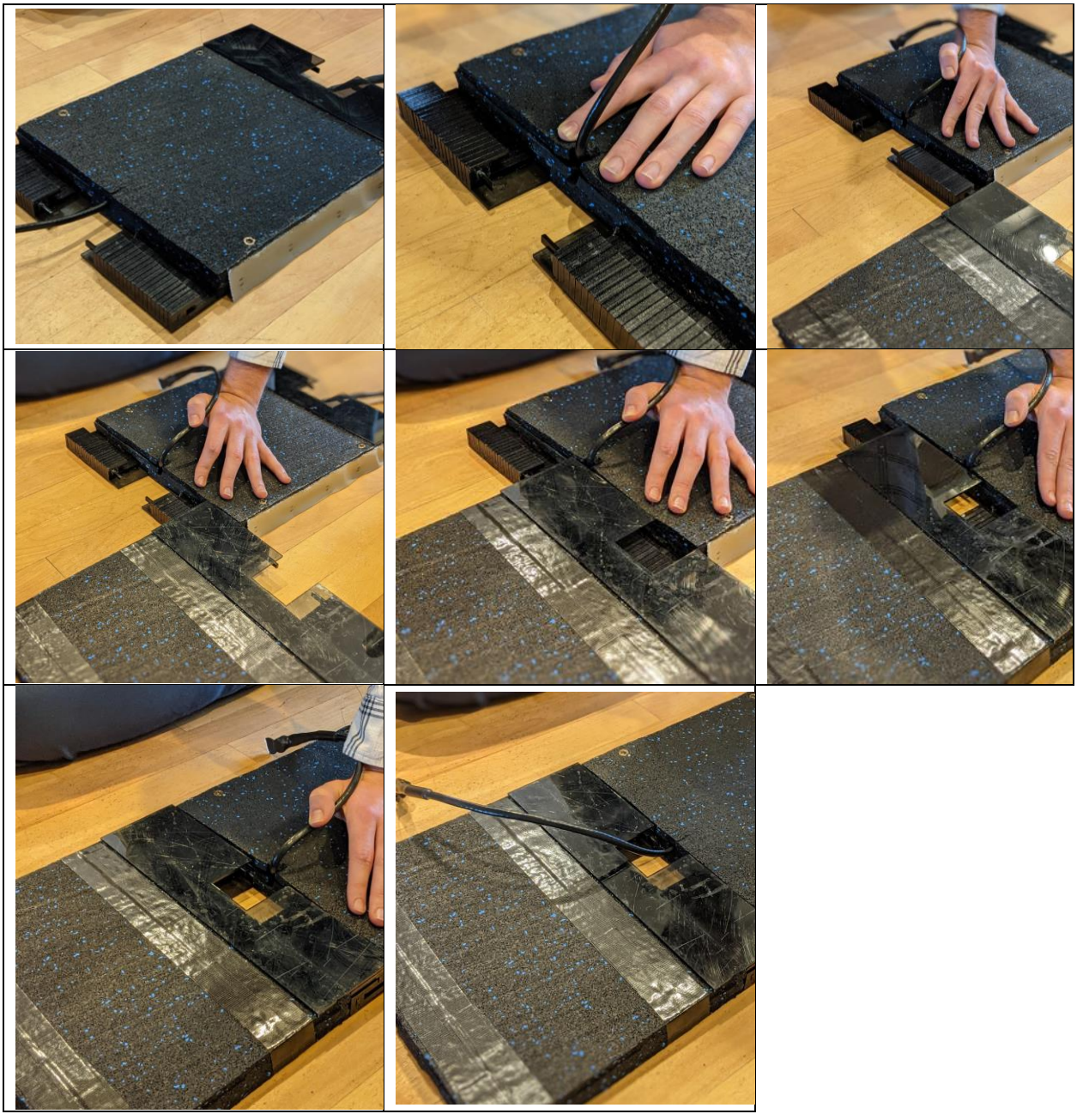
4 Using the System

4.1 Modularity

4.1.1. Interlocking Mechanism

The modularity of the FLAB Mat is accomplished through a sliding interlocking mechanism between adjacent mats. Since this project was designed for simplicity, using this system is quick and easy. The process of connecting the mats is illustrated in Table 4.

TABLE 4 - INTERLOCKING MECHANISM

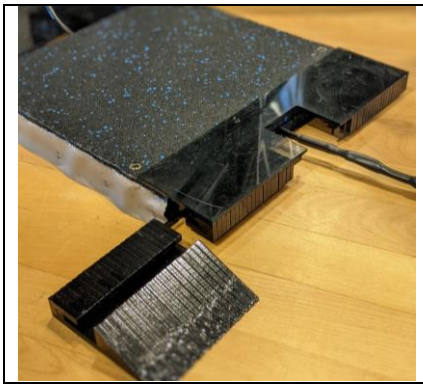
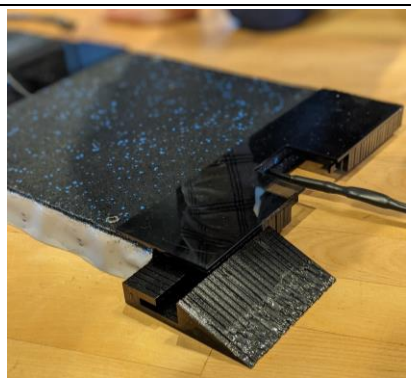
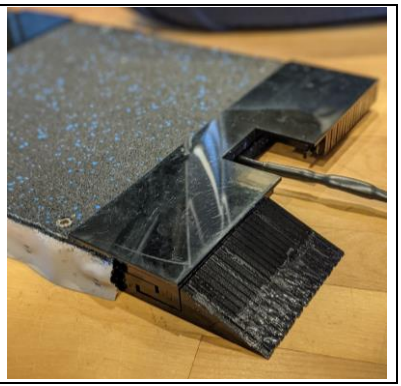


The interlocking process is illustrated by starting with the top left cell of Table 4 and working to the right and then down with each row. To begin, one must lift the exposed wire through the rubber notch in the top surface of the mat. The lower interlocking lip of one mat is slid into the conjoining upper interlocking lip of an adjacent mat. Once fully slid together, simply lower the wire, and push the rubber notch back down so it is flush with the top surface.

4.1.2. Accessibility Ramp

To give access to all users of this project, an accessibility ramp was created to slide on the end sections of interlocking FLAB Mats. It utilizes the same interlocking mechanism as the previous section. The process of sliding this accessibility ramp to the main modular sections is illustrated in Table 5.

TABLE 5 - ACCESSIBILITY RAMP

For this prototype, only half of a ramp was created, but moving forward this accessibility ramp would span the width of any modular sections that are not conjoined with each other.

4.2 Repairability

The FLAB Mat was designed for ease of repairability, enhancing its versatility and ease of use. If the heating cable embedded in the mat were to malfunction, the FLAB Mat is readily equipped with the ability to be completely opened to access the heating cable inside. The process of opening the mat begins by removing the grommets at each corner of the mat using an Allen key, as shown in Figure 3.

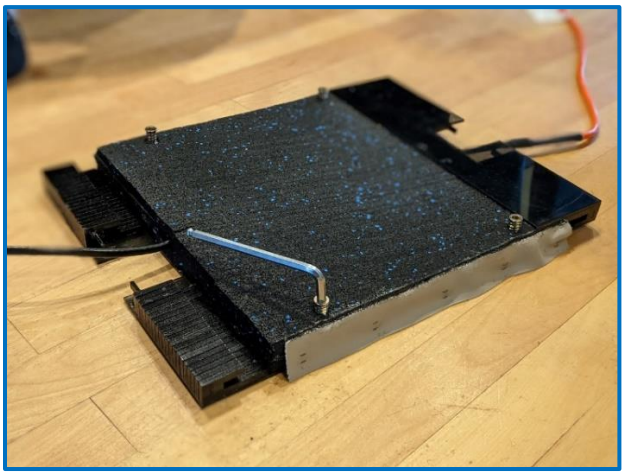


FIGURE 3 - UNSCREWED GROMMETS

Next, the snap fasteners keeping the waterproofing flaps secured to both sides of mat are unclipped. See Figure 4.

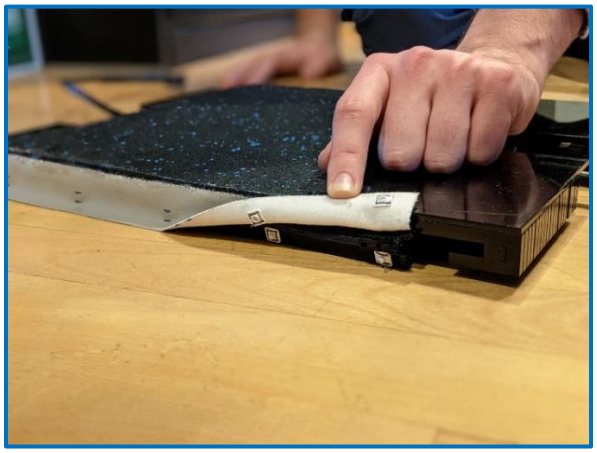


FIGURE 4 - UNSNAPPING OF THE SNAP FASTENERS

The newly exposed zippers can now be unzipped, as seen in Figure 5.

FIGURE 5 - UNZIPPING THE ZIPPERS

With all three securement methods between the top layer and the bottom layer disabled, the top layer can be peeled back for access to the heating cable embedded within. See Figure 6.

FIGURE 6 - EXPOSED HEATING CABLE

This concludes the process of accessing the heating cable for repairability. To return the FLAB Mat to its working form, simply perform all the following steps in reverse order. The total process starting with a functioning mat and completely exposing the cable for repairability takes approximately 3 minutes. Keep in mind that this process would likely only have to be completed on a few mats each season.

4.3 Heating

To effectively melt snow and ice, the FLAB Mat utilizes a heating cable that is embedded within its rubber body. This prototype of the FLAB Mat requires only two constraints to be met for heating and melting to occur. One, the temperature probe, located at the end of the heating cable, must be below 37˚F/2.8˚C to turn on. Two, the heating cable itself must be plugged into a standard 120 V outlet. Figure 7 shows how the student team ensured that the first constraint was satisfied. Figure 8 shows the second constraint being satisfied.

FIGURE 7 - TEMPERATURE PROBE IN ICE WATER

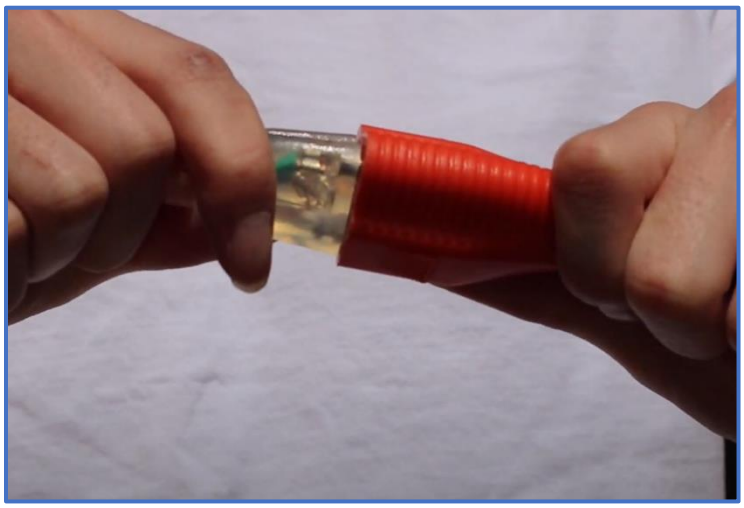


FIGURE 8 - PLUGGING IN THE HEATING CABLE

The FLAB Mat is now ready to melt ice and snow!

4.4 Stability

The FLAB mat was designed for safety, and as a result it can be safely secured to the concrete sidewalk that it rests on. To utilize this feature of the FLAB mat, two processes must be executed. Holes must first be drilled into the concrete sidewalk using a concrete drill bit so that the holes are aligned with the grommets on the mat. From here, simply screw a concrete screw through each of the grommets and into the sidewalk below. This step is illustrated on grass in Table 6. Note that this process is easily transferrable to a concrete sidewalk.

TABLE 6 - INSERTING THE CONCRETE SCREWS

With the concrete screws embedded in both the mat and the concrete (or soil in this case), the mat is safely secured to prevent shifting, slipping, and potential theft.

4.5 Storability

The FLAB Mat is made from a rubber with a high coefficient of friction, so simply stacking the mats on a non-incline surface will offer sufficient securement and safety. The simplicity of stacking two mats is demonstrated in Figure 9.

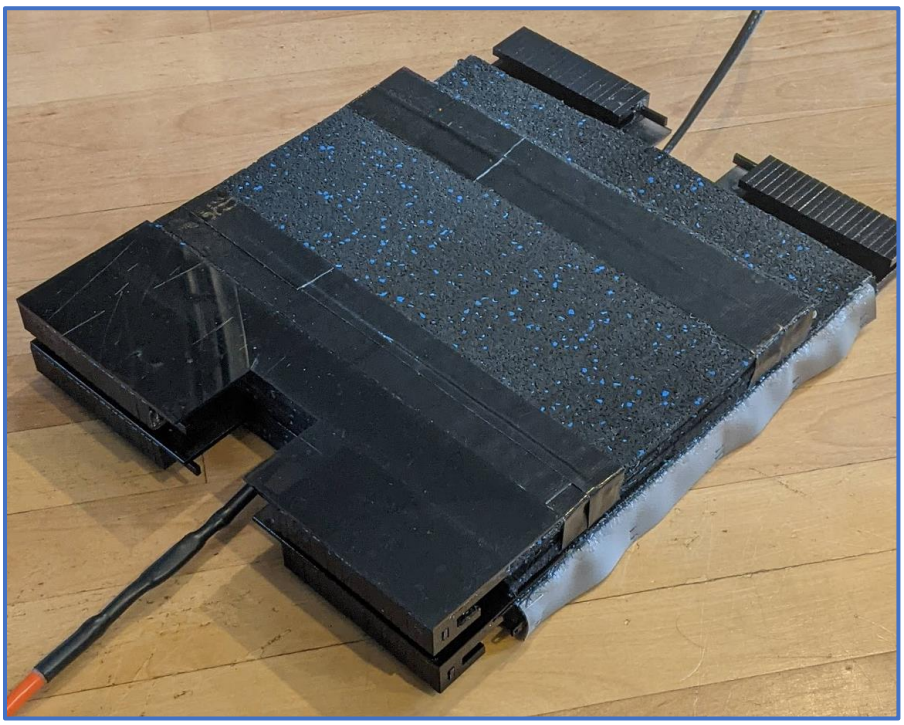


FIGURE 9 - STACKING THE MATS

5 Troubleshooting & Support

This section provides proper troubleshooting procedures and support for users. Please follow these procedures to troubleshoot the product.

5.1 Error Messages or Behaviors

1. If mat is not heating or melting snow, check if the temperature probe is in a sufficient location where the minimal environmental temperature is 37°F/2.8˚C. Additionally, check if the cable is plugged into the outlet properly, and if the outlet itself is receiving power.
2. If two mats cannot be interlocked, check if there is dirt, sand, stones, or debris stuck in either one of the mechanisms. Clean the mechanisms with water and a brush. For tougher build-up, use a soapy brush.

5.2 Special Considerations

1. Ice cubes may be required to cool the temperature probe in water below 37°F.
2. Adhesive and sewing thread may be needed to fix the joints and connections between components.

5.3 Maintenance

1. The heating cable may need to be replaced if the mat is not melting snow. Simply unscrew the concrete screws located at each corners of the mat from the ground. Unscrew the grommets using an Allen key. Next, unclip the snap fasteners on each side. Then, unzip the zippers on both sides. Peel off the top layer of the mat and replace the heating cable.
2. Keep the surface clean, rinse the surface with water and brush off impurities regularly.
3. Check the glue and the stitching regularly. If connection spots are loose, add glue or stitching to keep the components secured to each other.

5.4 Support

For additional support, please contact the “Fio and the Zoomers” design team. The team is glad to assist with any problems.

Email address: fioandthezoomers@gmail.com

6 Product Documentation

6.1 Modularity

Construction of the modularity subsystem of the FLAB Mat utilized acrylic sheets of varying thicknesses in combination with a laser cutter, and sketching software compatible with the laser cutter. Originally, Fio and the Zoomers planned to 3D print the modular section of the FLAB mat. However, certain aspects of 3D printing deterred them from this idea. For one, the 3D printer available to the student team only accommodated print jobs up to 22cm x 22cm. The width of the FLAB mat is 12'', so 3D printing the modular sections would require two print jobs per side. The student team would have to design two separate sections that can both connect with each other and the rubber mat itself. With three sides plus a ramp section there would be seven total print jobs. This leads to the second drawback of the 3D printing method: time. The laser cutter was able to cut all the pieces needed for this project in ~90 minutes, comparing this to running a 3D printer over seven print jobs, this would be between 12-18 hours at best. The student team built this prototype during a period in which the Makerspace would only be open for a few hours each week, and therefore could not realistically 3D print the necessary parts within the given time constraint. The time needed to design something in 3D is also much longer than sketching something in 2D. In short, the student team was able to save a lot of time by using a laser cutter instead of a 3D printer. This was essential to the success of the team as the student team simply would not have been able to finish the project within the given time frame had 3D printing be used.

6.1.1. Bill of Materials

TABLE 7 - MODULARITY SUBSYSTEM MATERIALS

Product Description	Quantity	Subtotal	Total Taxes	Total Amount
Permatex® Ultra Bond® Multipurpose Adhesive	1	$7.99	$1.04	$9.03
Black Acrylic Sheet (24''x18'', ¼'' Thick)	1	$22.00	$0.00	$22.00
Scrap Acrylic Sheet (1/8'' Thick)	~2	$0.00	$0.00	$0.00
			SUBSYSTEM TOTAL	$31.03
			PROTOTYPE RUNNING TOTAL	$31.03

NOTE: The thicknesses of the acrylic sheets are nominal sizes, specific to the University of Ottawa's Makerstore. All Instructions and dimensions used in the proceeding sections are specific to the materials sold at the Makerstore.

6.1.2. Equipment List

- Laser cutter
- Inkscape (Laser Cutting Software)
- Disposable nitrile medical examination gloves
- Scrap cardboard
- Newspaper
- Weights
- Utility Knife
- Scrap Rubber

6.1.3. Instructions

Day 1:

1. To begin, Inkscape (or any laser cutting software) should be used to create the following sketches: rectangular connecting rods, see Figure 11; a J-shaped piece, see Figure 12; a ramp/J-shaped piece, see Figure 10; and a large top/bottom connection piece, see Figure 13. All dimensions are in millimeters. Ensure that the width of all lines is 0.001 in.

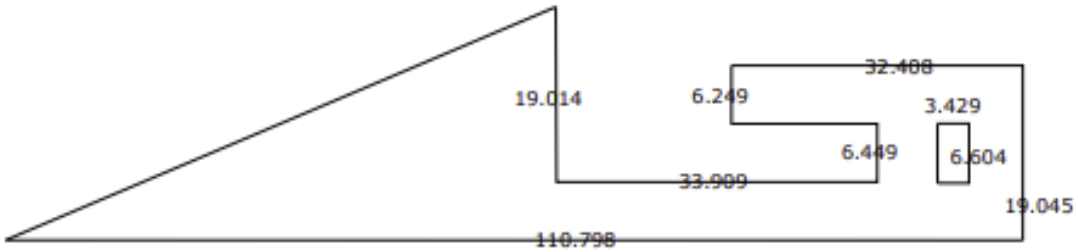


FIGURE 10 - RAMP/J-SHAPED PIECE

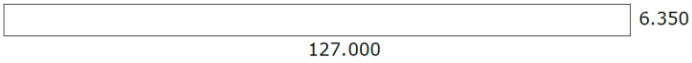


FIGURE 11 - CONNECTION ROD

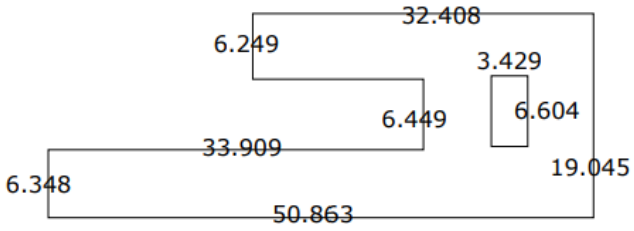


FIGURE 12 - J-SHAPED PIECE

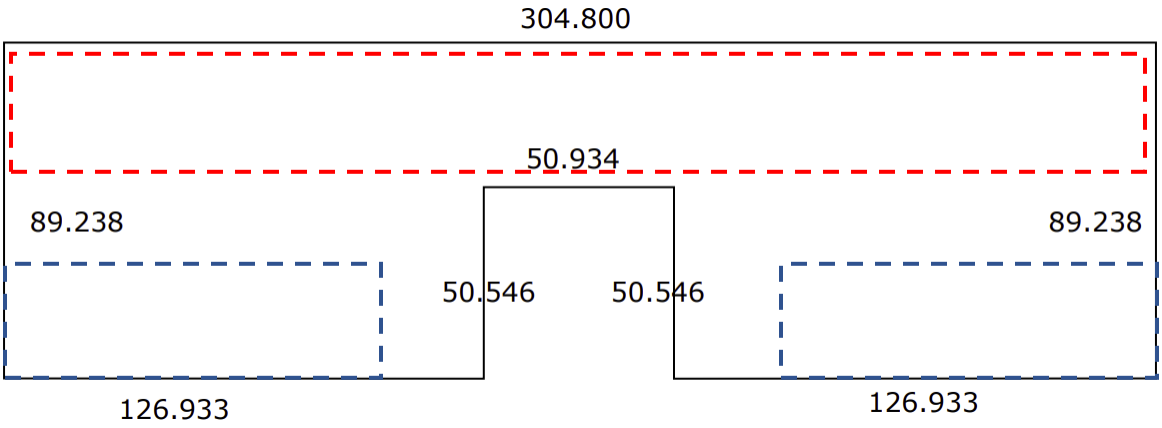


FIGURE 13 - TOP/BOTTOM CONNECTION PIECE

2. Create a new Inkscape file that is 24” x 18.”
3. Copy and paste the sketch of the J-shaped piece 120 times, and the ramp/J-shaped piece 20 times onto this new file. NOTE: The more organized the sketches, the more space that will be saved. See J Piece Good5.svg and Ramp2.svg in Table 18 for reference.
4. Insert the black acrylic sheet (24’’x18’’, ¼’’ thick) into the laser cutter, and cut the file created in steps 2-3, see Figure 14.

FIGURE 14 - LASER CUTTER

5. Create a new Inkscape file and copy and paste 7 connection rod sketches. See Rods.svg in Table 18 as a reference.
6. Cut this on any 1/8” scrap acrylic (dark grey was used in the FLAB Mat).
7. Create a new Inkscape file and copy and paste 3 top/bottom connection piece sketches. See Top/BottomFinal2.svg in Table 18.
8. Repeat step 6.
9. Wear nitrile gloves on both hands.
10. Lay down some sheets of newspaper on the work surface.
11. Group the J-shaped acrylic pieces (both regular and ramp) into groups of 20. There should be 6 regular J-shaped groups and one ramp group.
12. Align the pieces of one group to form a modular brick using a square corner.
13. Spread adhesive on the four long edges of one connection rod using the scrap cardboard.
14. Slide the connection rod through the aligned pieces so that it is flush at one end.
15. Repeat steps 11-13 for the remaining groups of pieces. NOTE: the rod will stick out of one side of each modular “brick,” so ensure that for the regular J-shaped “bricks,” three “bricks” have the rod sticking out of the left end and three the right end. This does not apply for the ramp section.

Day 2:

16. Repeat steps 9-10.
17. Apply adhesive to the largest face of a regular J-shaped “brick.”
18. Adhere this section to the top/bottom connection piece in the area outlined by the blue rectangles in Figure 13. Ensure that the exposed connection rod within each “brick” is facing

towards the center of the top/bottom connection piece. Using Figure 13 as a reference, ensure the “tongue” is facing upwards for both “bricks.”

19. Repeat steps 17 -18 for the remaining four “bricks” and two top/bottom connection pieces.

Day 3:

20. Repeat steps 9-10.
21. Using the scrap rubber from step 1 of Section 6.3.3, cut a 12” x 9.5” section from each rubber tile.
22. Wrap these three-rubber sections together along the 12” edges using Gorilla tape. Make sure there is at least 2” of exposed rubber at one end of this stack of mats (i.e. do not wrap the tape within this distance at one end).
23. Apply adhesive to all three of the top/bottom connection pieces in the area outlined by the red box in Figure 13.
24. Place one top/bottom connection on the top of the exposed rubber edge of the 12” x 9.5”.
25. Support the overhanging interlocking mechanism with scrap cardboard and apply weights to the top of the top/bottom connection piece where it is being glued.
26. Place another top/bottom connection piece to the bottom side of the bottom layer of the main prototype at the end with the temperature probe.
27. Apply weights to the top of the prototype above the area being glued.
28. Place the final top/bottom connection piece to the top side of the other end of the main prototype.
29. Repeat step 25.

Day 4:

30. Cut a small notch in the rubber at the probe end of the prototype. The notch should look like Figure 15.

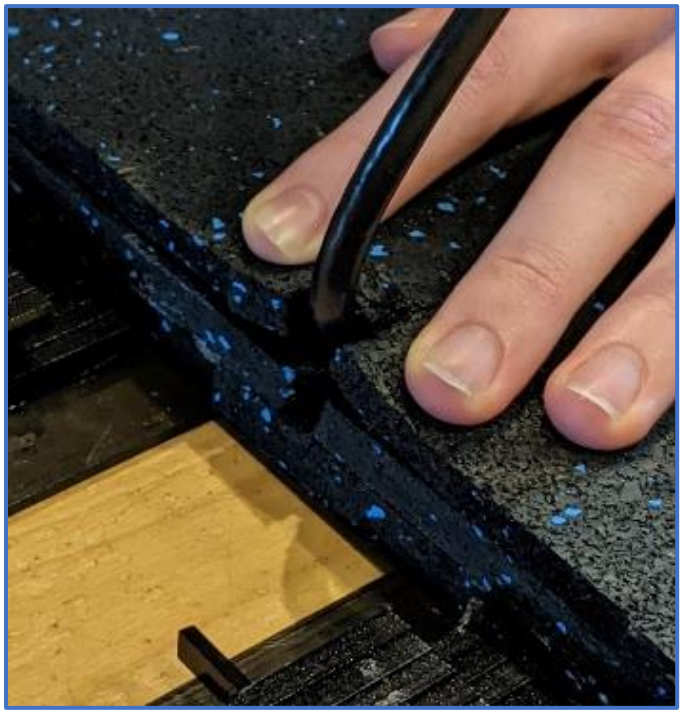


FIGURE 15 - NOTCH

6.2 Repairability

As part of the design criteria for this project, the FLAB Mat was designed with repairability from the start to reduce operational costs and improve the sustainability of the product. To do this, the student team devised a system of fasteners that would allow the rubber mat to be partially disassembled to provide access to the heating cable embedded inside for repairs and/or replacement. The envisioned design was to include a zipper that connects the top rubber layer to that of the middle layer that would be unzipped when requiring access to the FLAB Mat's internals. Moreover, waterproof flaps were to be installed onto the top rubber layer, draped over the top of the zippers for protection from moisture. However, these flaps are to be secured to the bottom layer using snap fasteners instead.

Due to budget constraints, a pair of cheap non-separating zippers were purchased for installation on the prototype as proof-of-concept rather than the separating zippers required for complete removal of the top rubber layer. The student team settled on this option as the non-separating zippers would provide sufficient access to the heating cable at a fraction of the cost compared to the separating zippers. Additionally, sewing thread was used for attaching the snap fasteners onto the side flaps as the student team encountered issues with using a hot glue gun on an earlier prototype. Furthermore, the student team did not have access to a sewing machine, which may have significantly reduced the time spent on steps 4-6 described in Section 0.

6.2.1. Bill of Materials

TABLE 8 - REPAIRABILITY SUBSYSTEM MATERIALS

Product Description	Quantity	Subtotal	Total Taxes	Total Amount
Black Plastic Non-Separating Zippers (12'')	2	$4.12	$0.53	$4.65
Permatex® Ultra Bond® Multipurpose Adhesive (re-use from other subsystem materials)	1	$0.00	$0.00	$0.00
Slate Grey Vinyl Fabric (54'' width x 0.5 m length)	1	$4.00	$0.52	$4.52
Plastic Sew-On Snap Fasteners (15 Pack)	1	$2.84	$0.37	$3.21
			SUBSYSTEM TOTAL	$12.38
			PROTOTYPE RUNNING TOTAL	$43.41

6.2.2. Equipment List

- Hand-stitch sewing needle
- Sewing thread (cotton)
- Fabric scissors
- Dressmaker's pins
- Fabric chalk (or pen)
- Ruler
- Pliers
- Stapler
- Lighter

6.2.3. Instructions

Day 1:

1. Using a ruler and fabric chalk, mark the dimensions of the side flap on the wrong side of the vinyl fabric (1”x12”).
2. Cut out the rectangle that has been marked onto the fabric with fabric scissors.
3. Repeat steps 1-2 to create a second flap.
4. Using dressmaker’s pins, attach the wrong side of the vinyl flap to the right side of the zipper, ensuring that the zipper pull tab is aligned with the leftmost edge of the flap. Note that this will now be referred to as the **left** flap.
5. Hand-stitch the flap to the zipper using a sewing needle and cotton sewing thread that closely matches the colour of the flap fabric. Blanket stitch is recommended.
6. Repeat steps 4-5 for the second flap and zipper, instead ensuring that the zipper pull tab is at rightmost edge of flap. Note that this will now be referred to as the **right** flap.
7. Hand-stitch 5 snap fasteners to the bottom edge of the left flap in 3-inch increments, starting from the frontmost edge of the zipper. Ensure that the cap of the fastener is attached.
8. Align the stud portion of each fastener with its respective cap and hand-stitch the stud to the wrong side of the flap.
9. Repeat steps 7-8 for the right flap.

Day 2:

10. Temporarily staple the top edge of the left flap to the left edge of the top layer of the rubber body. Ensure that the zipper pull tab is closest to the front of the mat when the zipper is closed.
11. Using multipurpose adhesive, glue the backside of the top edge of zipper tape to the top layer of rubber. Ensure the adhesive does NOT touch the zipper teeth. Allow 12 hours to cure fully, or 1 hour to dry partially if there is a severe time constraint.
12. Repeat steps 10-11 for the right flap, ensuring that the top edge of the right flap is aligned with the right edge of the top layer of the rubber body.
13. Using multipurpose adhesive, glue the backside of the bottom edge of zipper tape to the bottom two layers of rubber. Ensure the adhesive does NOT touch the zipper teeth. Allow 12 hours to cure fully, or 1 hour to dry partially if there is a severe time constraint.
14. Repeat step 13 for the right flap.
15. Trim excess zipper tape and flap fabric, using pliers to remove zipper teeth and/or the bottom zipper stop where needed. If the zipper stop is removed, add a small amount of adhesive to the bottom of the zipper to ensure the pull tab cannot be fully removed.
16. Repeat step 15 for the right flap.
17. Burn the edges of the trimmed zipper with a lighter to prevent fraying, ensuring that the flame is not held too close to the zipper tape.
18. Repeat step 18 for the right flap.

6.3 Heating

When designing the heating subsystem for the FLAB Mat, the student team originally planned for a self-regulating heating cable to be embedded inside the rubber material. A self-regulating heating cable is ideal for the FLAB Mat's application because it allows the product to operate autonomously without any protruding components (such as sensors), minimizes operating costs by only turning on when needed, and acts as a safety precaution to prevent overheating. However, while waiting for approval of the bill of materials, the desired product of suitable length became unavailable for purchase, thus resulting in an alternative solution being needed. Other self-regulating cables on the market were either outside of the budget range and/or unsuitable in length for the heated sidewalk mat.

The student team settled on a pipe heating cable with a built-in thermostat as it was a similar price to the original self-regulating heating cable and was readily available for purchase. The heating cable is designed to operate at acceptable temperatures (i.e. turning on just above freezing, 37°F, and turning off at 50°F) and is also durable since it is designed for outdoor use. However, the student team had to make design changes to the FLAB Mat to accommodate for the temperature probe on the heating cable in ensuring that it detects a sufficiently cold temperature to activate its heating elements through external means (outside of the mat). This is not ideal; however, it was a compromise the student team was willing to make to have a working final prototype that tests could be conducted on to validate the rest of the FLAB Mat's design.

It is important to note that neither heating cable option possessed the necessary electrical modularity envisioned for the production-model version of the FLAB Mat as this would likely have to be a customized for use in the design. However, none of the members of the student team had experience performing modifications on electrical components, and any electrical modifications made to this type of electrical cable would likely result in damage or injury, so this feature was not included in any of the FLAB Mat prototypes.

6.3.1. Bill of Materials

A complete list of materials required for the construction of the heating system is tabulated below in Table 9. It is important to note that the student team already possessed a set of interlocking rubber floor tiles, so they did not contribute to the expenses for the FLAB Mat's heating subsystem. The anticipated cost for a new set of 6 rubber mats is approximately $50-100 including taxes.

TABLE 9 - HEATING SUBSYSTEM MATERIALS

Product Description	Quantity	Subtotal	Total Taxes	Total Amount
HEATIT Pipe Heating cable with Built-in Thermostat (6 ft)	1	$28.99	$0.00	$28.99
Permatex® Ultra Bond® Multipurpose Adhesive	1	$7.99	$1.04	$9.03
Gorilla Tape To-Go (30 ft roll)	1	$3.58	$0.47	$4.05
Interlocking Rubber Floor Tiles (2"x24"x0.3")	3	$0.00	$0.00	$0.00
			SUBSYSTEM TOTAL	$42.07
			PROTOTYPE RUNNING TOTAL	$85.48

6.3.2. Equipment List

- Utility knife (or box cutter)
- Cutting board
- Scrap cardboard
- Newspaper
- Scissors
- Acrylic ruler
- Disposable nitrile medical examination gloves
- Metallic silver, fine point permanent marker
- 5-10 lbs. weights

6.3.3. Instructions

Day 1:

1. Using a ruler, measure a 12”x12” square on each of the rubber tiles and draw the squares’ borders with a permanent marker.
2. Place a rubber tile on top of a cutting board to ensure no scratches are made to the surface underneath.
3. Using a utility knife and a ruler to guide the blade, cut along the drawn lines of the rubber tile until the square is fully separated from the original rubber tile.
4. Repeat step 3 for the other two rubber tiles.
5. Using the silver marker, measure and draw a snake pattern (about 1/4” wide) on one of the square tiles as shown in the figure below:

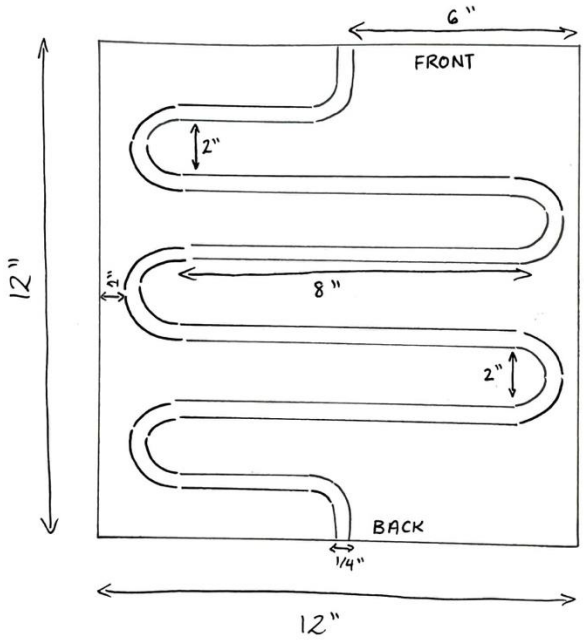


FIGURE 16 - SNAKE PATTERN TO DRAW

6. With the utility knife, trace the drawn lines with the blade and cut out the snake pattern on the rubber tile. These two rubber halves will form the middle layer of the FLAB Mat.

7. Use scissors to cut a small rectangle (approximately 1”x3”) made from cardboard to use as a “brush” for spreading adhesive.
8. Cut 30-40 strips of cardboard 1/4” wide and of varying lengths between ½” to 1” for use as spacers.
9. Wear nitrile gloves on both hands.
10. Lay down some sheets of newspaper on the working surface.
11. Select one of the remaining square rubber tiles to be the FLAB Mat’s bottom layer. Temporarily use the other square tile as a flat surface to work on and place on top of the newspaper.
12. Place one of the middle halves on top of the remaining tile. Dispense a liberal amount of adhesive on the top of one of the middle layer halves and evenly spread it on the surface using the cardboard “brush”, ensuring that the surface is completely covered.
13. Line up the corners of the middle layer half on the flat rubber surface.
14. Repeat steps 12-13 for the other middle layer half.
15. Place cardboard spacers into the heating cable channel and evenly distribute them in the channel to ensure there is adequate spacing for the heating cable. If done correctly, the rubber stack should look like the setup shown in Figure 17 below:

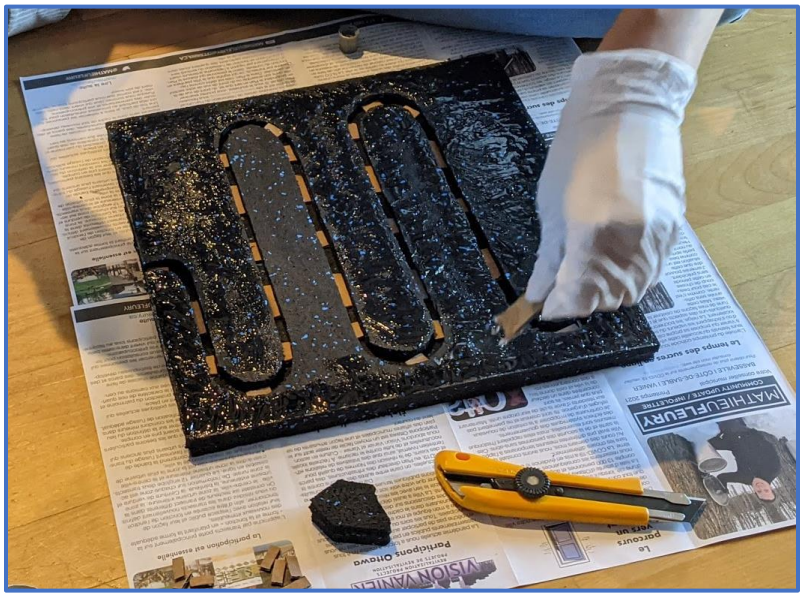


FIGURE 17 - ADHESIVE APPLICATION ON THE MIDDLE RUBBER LAYER

16. Take the bottom layer tile and place it on top of the middle halves covered in adhesive. Ensure that the edges are flush with one another.
17. Evenly distribute the weights on the top of the rubber layer stack as the adhesive dries.
18. Allow the adhesive to dry for at least 12 hours.

Day 2:

19. Remove the weights off the rubber layer stack.
20. Flip over the stack, revealing the middle and bottom layers, now glued together.
21. Remove the cardboard spacers from the heating cable channel.

22. Ensure you are working on a cutting board to protect the flat surface while using the utility knife.
23. Using the scrap rubber tile pieces, cut 5 thin strips 1/8" wide and 8" in length with a utility knife.
24. Cut an additional 2 strips 1/8" wide and 3" length with the utility knife.
25. Cut 12 more strips 1/8" wide and 1/2" length with the utility knife.
26. Wear nitrile gloves on both hands.
27. Lay down some sheets of newspaper on the working surface.
28. Apply a small amount of adhesive along the length of one of the 8" rubber strips.
29. Use the cardboard "brush" to spread the adhesive so that one of the strip's surface is completely covered.
30. Glue the 8" strip to one of the long, straight portions of the heating cable channel.
31. Repeat steps 28-30 for remaining 8" strips.
32. Repeat steps 28-31 for the 3" strips, except glue these strips to the short, straight portions of the heating cable channel (located near the front and back of the mat).
33. Repeat steps 28-31 for the 1/2" strips, except glue these strips along the curved bends of the heating cable channel.
34. Place the heating cable into the carved channel in the middle layer. Ensure that the insulated portions of the cable (black-coloured) are within the channel and the non-insulated portions (orange-coloured) are exposed outside of the mat. Additionally, ensure that there is approximately 10" of cable exposed from the side of the heating cable with the temperature probe. This is to make sure that there is sufficient slack on the heating cable for probe to be placed on an appropriate cold surface.
35. Use Gorilla tape to secure the heating cable down onto the middle layer.
36. Place the remaining square tile on top of the rubber stack with the embedded heating cable.
37. Evenly distribute 10 lbs. of weight on the top of the rubber layer stack as the adhesive dries.
38. Allow the adhesive to dry for at least 12 hours.

6.4 Stability

To stabilize the heating mat, concrete screws were chosen for construction. Concrete screws are optimal for this application as sidewalks are often constructed from concrete. In addition, metal grommets were chosen to guide the screws through the mat. Since the rubber surface would theoretically become worn out over time by the sharp screw threads, the grommets are used to prevent the screws from damaging the rubber surface during the installation and removal processes. The grommets are also corrosion resistant as they are made of zinc-plated carbon steel and were selected for their durability in outdoor conditions. Plastic grommets could be an alternative option to guide the screws as they would be cheaper and more lightweight. However, they are not optimal for this prototype since concrete screws would easily damage plastic grommets.

6.4.1. Bill of Materials

TABLE 10 - STABILITY SUBSYSTEM MATERIALS

Product Description	Quantity	Subtotal	Total Taxes	Total Amount
Tapcon 3/16'' x 3-1/4'' Slotted Hex Head Concrete Anchors (10 Pack)	1	$8.96	$1.16	$10.12
Glarks 1/4''-20x25mm Threaded Insert Nuts, Zinc-plated Carbon Steel, Hex Socket (50 Pack)	1	$13.99	$0.00	$13.99
8 oz. Butane Fuel Canister Cartridge	1	$0.00	$0.00	$0.00
			SUBSYSTEM TOTAL	$24.11
			PROTOTYPE RUNNING TOTAL	$109.59

6.4.2. Equipment List

- Cutting board
- Screwdriver
- Allen key (M6)
- Portable gas stove
- Metallic silver, fine point permanent marker
- Ruler

6.4.3. Instructions

1. Using the ruler and silver marker, measure, and mark 4 dots that are 1/2" away from the left/right edges of the mat and 2" away from the front/back edges of the mat.
2. The screwdriver must be heated on the portable gas stove for 2 minutes, see Figure 18.

FIGURE 18 - HEATING UP THE SCREWDRIVER

3. Force the screwdriver through the top rubber layer where the first dot has been marked to melt the rubber and create a hole all the way through.

4. Force the screwdriver through the bottom two layers, using the previously created hole as a guide. See Figure 19.

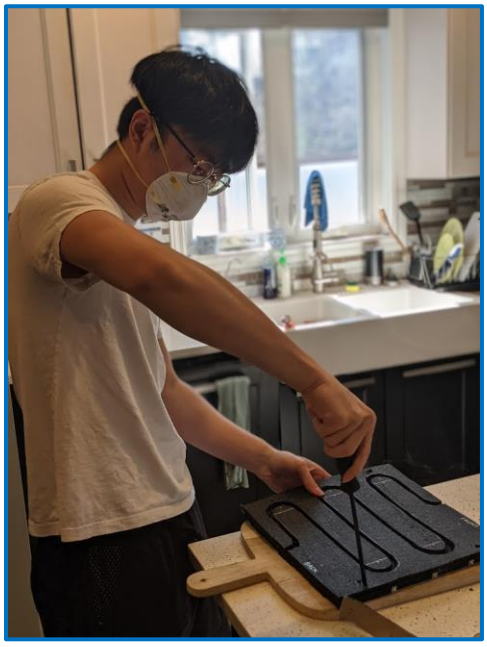


FIGURE 19 - MELTING HOLES USING A SCREWDRIVER

5. Repeat steps 3-4 three more times to make a hole where each dot has been marked.
6. Stack the layers (lining up each of the holes) and screw in 4 grommets using an Allen key at each corner.

6.5 Storability

For this prototype, there was no specific structure built for storability because the mat is naturally storable without extensions. The surface of the mat uses a recycled rubber that provides enough friction for the mats to safely stack on top each other. Straps were considered to tie the mats together in storage; however, the straps were decidedly unnecessary after testing revealed that the stacked mats do not begin to slide until they are inclined at an angle of 50°. Wood was also considered for the surface material, but the system must operate in humid and wet environments while also providing proper heat conduction. As such, wood was not a feasible choice as it rots over time and does not provide good heat conduction.

6.6 Testing & Validation

As part of the design process, the student team conducted a variety of tests on the FLAB Mat's subsystems to validate the designs. These tests varied between focused and comprehensive tests depending on the team's current stage of the design process. Focused tests only tested the desired component/subsystem individually whereas a comprehensive test assessed the desired component/subsystem as part of the completed prototype. Focused tests were more likely to occur earlier on in the design process when the prototype was not yet completed or matured in its design. In comparison, comprehensive tests were conducted near the end of the development cycle where the final prototype was already constructed.

6.6.1. Modularity

The modularity was first tested to show the feasibility of the concepts. A cardboard prototype of the interlocking system was first constructed by layering rectangles of varying dimensions to sculpt the shape of the mechanism. To test its feasibility, this cardboard interlocking system was slid together as shown in Figure 20.

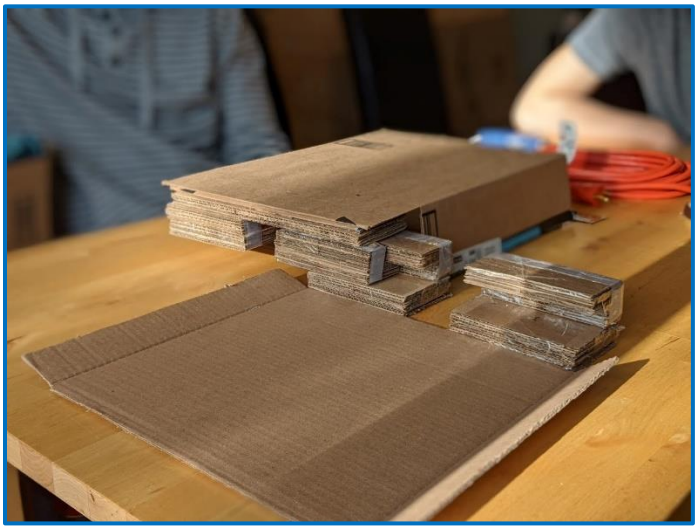
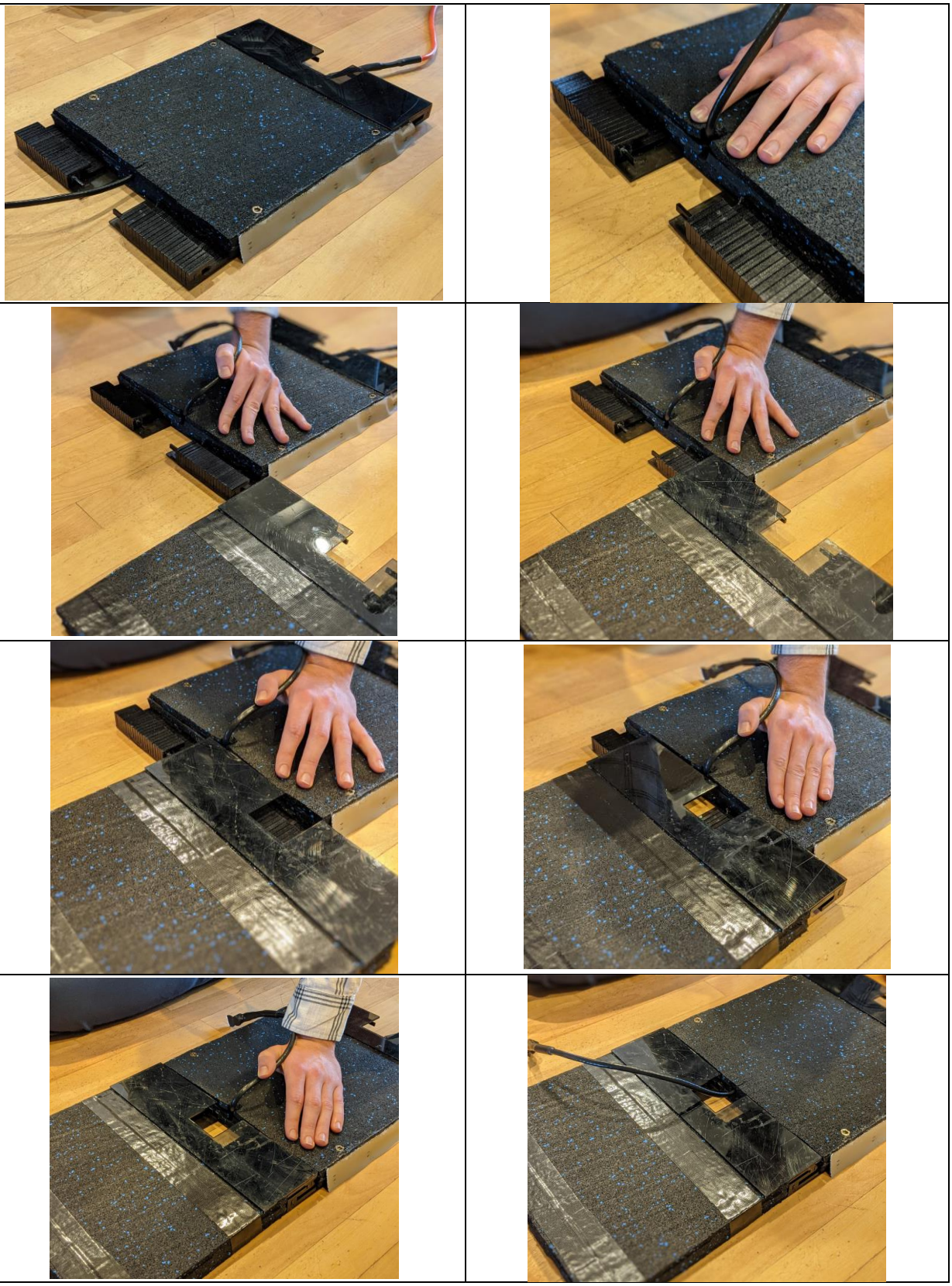


FIGURE 20 - CARDBOARD INTERLOCKING SYSTEM TEST

The concept of the interlocking system was proven well by this test. The importance of symmetry and precision in the final design was emphasized from the results of the test.

Further testing was done on the final prototype to show the compatibility with other subsystems. In Table 11, the acrylic interlock system was tested to evaluate the ease of sliding. The performance of the acrylic interlocking lips was excellent as the components serve the purpose of locking the mats together successfully. However, during testing of this prototype, a significant design flaw was revealed; the modularity subsystem was initially obstructed by the heating cable during the connection process. To solve this issue during testing, a small notch was cut into the top rubber layer to prevent the cable from interfering with the connection process. This notch then became a necessary component of the final design.

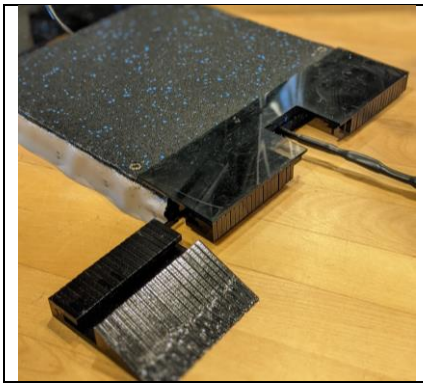
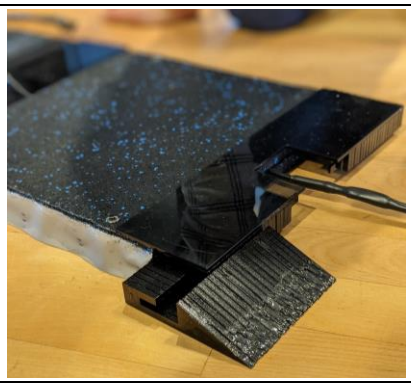
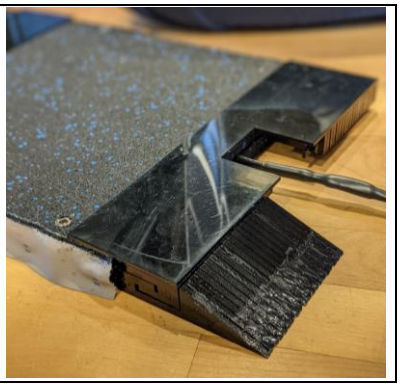
TABLE 11 - INTERLOCKING MECHANISM



Some aspects of this subsystem would have to be adjusted in the production model of this design. For one, the cable used in this prototype is too long and not electrically compatible with a series of multiple mats. Ideally, the remaining, protruding cable would be short enough to fit within the recessed portion of the interlocking lips and contain a plug that would attach to the adjacent mat. Another aspect that was not captured in this design was the lid to seal the interlocking hole. Ideally, a cap or lid would cover the hole where the cables connect to prevent snow and water from entering this area. However, because the cable is much longer in this prototype, the lid could not be constructed and would not be practical.

The ramp mechanism was also tested. This is illustrated in the photos compiled in Table 12.

TABLE 12 - RAMP

Ultimately, both the ramp and regular interlocking mechanisms were deemed to be successful. They effectively communicate the interlocking mechanism of the final design.

6.6.2. Repairability

After the completion of the construction, the grommets, zippers, and flaps were tested. The steps to access the heating cable are tedious in comparison to the ease of the interlocking mechanism. However, this is not a concern for the overall feasibility of the modular sidewalk since each mat is an individual piece; the whole heating system will not require a large amount of time to repair, only the respective broken mat. In Figure 21 below, the four grommets provide extra security to the top and bottom layer and were easily taken out with an Allen key using a small amount of force.

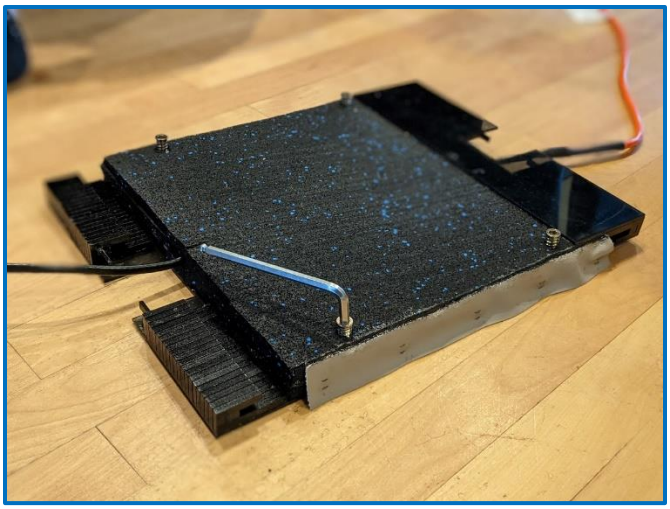


FIGURE 21 - UNSCREWED GROMMETS

This installation and uninstallation can be completed even faster by using an electric drill with the correctly sized hex key. This will possibly reduce the time to install large quantities of the heating mat across the university campus.

Next, the flaps were opened by unclipping the snap fasteners to reveal the zipper underneath as shown in Figure 22 below:

FIGURE 22 - UNCLIPPED SNAP FASTENERS

The snap fasteners can be easily unclipped. However, for the actual implementation of the heating mat, larger metal snap fasteners should be attached to the flap instead. The small plastic snap fasteners are chosen for this prototype to satisfy its dimensional and budget constraints. Next, the zippers were unzipped to gain accessibility to the heating mat. This is shown in Figure 23 below.

FIGURE 23 - UNZIPPED ZIPPER

However, due to budget constraints, the student team was not able to purchase a fully detachable zipper (which was the type of zipper specified in the original design). As a result, the mat can only be peeled from one end to the other but not fully detached as is shown in Figure 24 below.

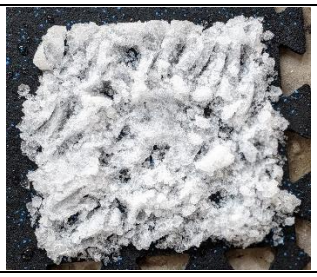
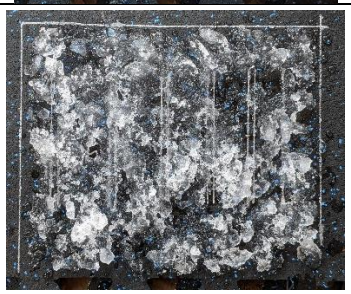
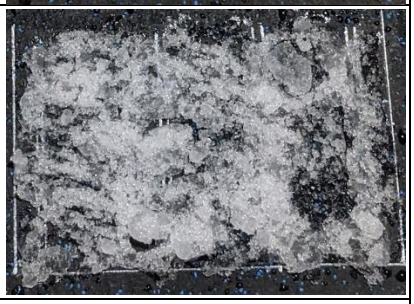
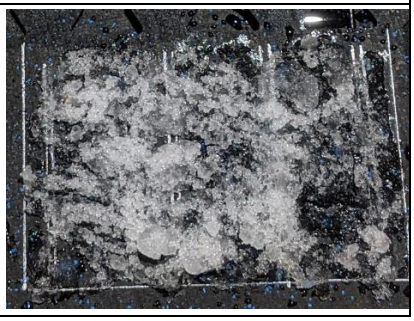
FIGURE 24 - PEELED-OFF TOP LAYER

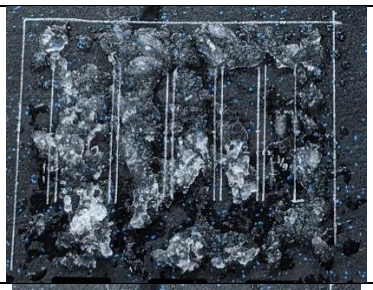
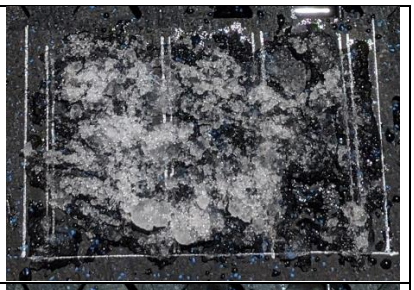
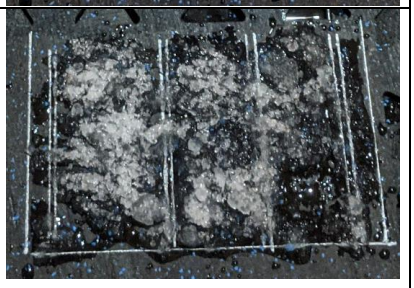
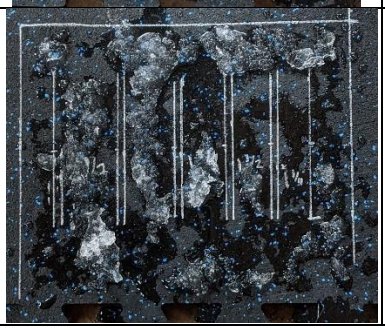
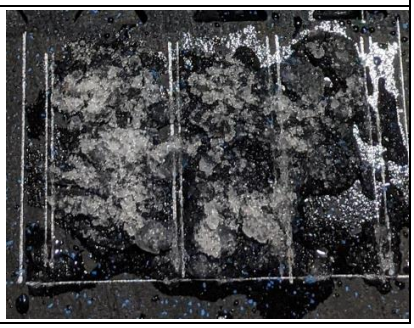
The test was successfully completed and deemed functional by the student team. However, because the zippers are not fully detachable, the heating cable cannot be replaced in this specific prototype. In the production model, detachable zippers should be used for the heating mat to allow full access to the heating cable. With this change, the repairment procedures can be easily conducted.

6.6.3. Heating

Initially, heating was tested by varying two variables independently of each other in a focused, physical, medium fidelity test. First, the cable spacing within the rubber was changed while keeping the top-layer of the rubber at a constant thickness of 1/4''. In this test, two trials were performed to include all of the desired spacings (i.e. the cable could only accommodate so many spacings per trial). Table 13 shows the progress of melting the snow with each of the spacings tested in comparison to a control test with no heating cable.

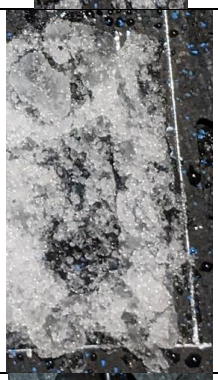
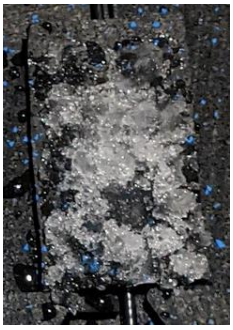
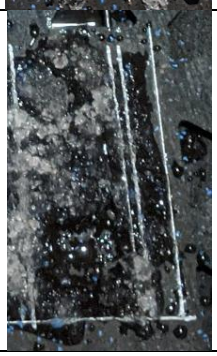
TABLE 13 - SNOW MELTING VS. TIME

Time (mins)	Control	Spacing	
		1 1/4-in, 1 1/2-in, 1 3/4-in, 2-in, 2 1/2-in	2 3/4-in, 3-in, 3 3/4-in
0	N/A		
20			
40	N/A		
50			
60	N/A		

70			
80	N/A		
90	N/A		

Upon the completion of this test, there was a noticeable difference between all tests with a heating cable and the control without the cable. Comparing the various spaces, it seemed like the 1 1/2'' spacing was optimal. It provided sufficient heat, while also reducing the length of cable needed (compared to maximum length needed for the 1 1/4'' spacing). Moving forward, the choice of spacing had the potential to be further increased depending on the results of the next test that was performed, which was the heating cable depth test. This test involved reducing the space between the heating cable and the snow from 1/4'' to 1/8''. The results are summarized in Table 14.

TABLE 14 - MAT THICKNESS COMPARISON (1/4 IN VS. 1/8 IN)

Time (min)	Thickness	
	1/4-in	1/8-in
0		
40		
80		

It was observed that the melting rate of the 1/8” thickness mat was significantly faster than the thicker mat. Generally, it validated the prediction that the snow would melt faster if it were closer to the heating cable. These results were carried onto the final prototype and it was decided that a thinner top layer would be constructed since the result of the two thicknesses differed significantly. In addition, the spacing of the heating cable was to be increased to 2”, due to the improved heating capabilities of the thinner mat.

As mentioned above, a cable spacing of 2” was used in the final FLAB Mat prototype. However, due to time constraints, the team was forced to use the 1/4” heating cable depth instead of the 1/8” depth. In future prototypes, a depth of 1/8” should be used. After completing the final FLAB Mat prototype, a final melting test was performed. These results are summarized in Table 15.

TABLE 15 - MELTING TEST PROGRESSION

Time (min)	Prototype test
0	
15	
30	

45	
60	
75	
90	

The results of this test revealed that the melting abilities varied slightly across the mat. Throughout the image timeline, the frontmost row of ice cubes (closest to the lens) seemed to be melting at a slower rate than the others. At the 90-minute mark, the front row seems to have melted to the same level as the back rows appeared to be at the 45-minute mark, indicating that the front section of the mat melts at ½ the rate as the rest. This can easily be explained by the placement of the cable within the mat itself. The ice directly above the heating cable melted faster than the ice that was in between the heating cable. Ideally, a manufactured model of this mat should have a smaller cable spacing to reduce this error.

Note that the back section of the mat containing the acrylic connector for the interlocking pieces was not tested. Internally, this section is identical to the front part of the mat. Aside from the added layer of acrylic, this section is expected to display the same heating performance as the front section, indicating that it also has a slower melting rate.

After conducting this test, the student team concluded that if this prototype were to be manufactured, the pattern for the cable implementation would need to be altered. Specifically, the cable would need to reach the two corners that it currently does not occupy (as can be seen in Figure 17).

Despite the clear discrepancies in the melting abilities across the mat, there is still a large, perceivable difference in the size of all the ice cubes when comparing the first and last pictures. The use of ice to conduct the test was also slightly unrealistic; the prototype was built to melt winter snow rather than whole chunks of ice. Considering these points, all sections of the prototype did still demonstrate adequate melting ability.

6.6.4. Stability

This test was performed to effectively communicate the stability subsystem of the final prototype. The test was deemed a success if it could show how the heated sidewalk mat will be attached to the sidewalk itself. The grommets from the repairability subsystem also serve another purpose; they house the concrete screws that will be drilled into the sidewalk. The student team did not have access to any concrete that they feel could be drilled into, so to demonstrate the principles of the prototype, the team performed the test using grass instead. This aspect of the prototype is medium-high fidelity. If concrete could have been used, this aspect of the prototype would have been high fidelity. As this test was qualitative, there were no specific measurements recorded. The goal of this test was to communicate the ideas of the student team to the client.

The student team was pleasantly surprised at how well the mat was secured. The process of securing the mat using the screw is outlined in Table 16.

TABLE 16 - SCREWING THE CONCRETE SCREWS

The team set out to simply show how the mat would be secured to the sidewalk. However, the team found that even though grass and soil were used instead of concrete, the mat was quite secure. Members of the student team could apply significant force to the edges of the mat without it sliding. It was not until a small kick was applied that the mat began to shift. The student team cannot be certain how stable the mat would be if concrete were used, however, the results in the grass are very favourable. In terms of communicating this concept to the client, this prototype was very successful. It demonstrated the concepts of the design to a high degree of effectiveness.

6.6.5. Storability

The FLAB Mat was designed to be stored in stacks. To test the feasibility of this method of storage, an inclined mat test was conducted, and the results were favorable. The mats remained unmoving with a high angle of inclination as shown in Figure 25.

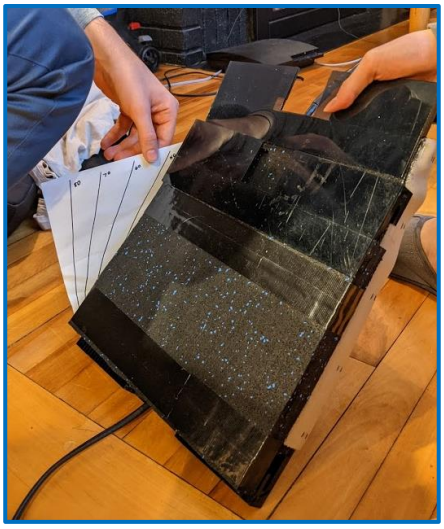


FIGURE 25 - FRICTION TEST BETWEEN MATS

Since it is unreasonable to store the mats at an inclined angle of more than 50 degrees, this result showed that the mats provide enough friction to stack on each other for storage without any external straps to secure them in place. However, in a realistic storage setting, there will likely be more than two mats stacked on top one another. As a result, the weight of the stacks will increase, meaning they will generate a greater horizontal force when the surface is inclined. This implies that they would need a smaller angle for the mats to slide off each other. Since the student team has a limited budget, it is impossible to perform tests with a larger number of mats for this subsystem. In conclusion, it is recommended that mats be stored in areas with little to no incline.

6.6.6. Surface

A surface safety test was conducted for de-risking to determine if the material to be used in the complete prototype would be safe to walk on. This test was specifically focused on the rubber material and was not conducted with the completed prototype. To complete the test, the rubber material was placed on top of a flat, rigid surface that could be easily lifted and tilted at various angles, and the angle at which different shoes would slide off was measured. The test was also replicated in wet conditions to increase its fidelity. This surface test revealed significant information regarding the safety of the mat, and the results were quite favourable. A visual representation of the experimental setup is shown below in Figure 26:

FIGURE 26 - SURFACE FRICTION TEST

The test was decided to be conducted with four different types of footwear to obtain a wide range of data. In this experiment, a boot, running shoe, sandal, and house slipper were placed on the surface of the rubber mat. As expected, the results varied slightly for each, but still yielded an overall conclusion.

Before mathematically analyzing this test, a few qualitative results were documented. In the trials, it was revealed that the chosen material provides above average amount of traction and friction. Despite the use of several different shoes (each with their own respective weight and sole material), the mat showed exceptional overall friction and grip. This is illustrated in detail in Table 17.

Moreover, the rubber displayed better results in the “wet” trials. These results were favourable since winter performance is the sole basis for the success of this heated mat.

After finishing the physical aspect of this test, the average angle of each trial was determined. Using this value, the coefficients of static friction were calculated using the following equation:

$$\tan\theta = \mu_S$$

The recorded experimental values as well as the results of these calculations can be seen below in Table 17. For reference, note that the USA Occupational Safety & Health Administration recommends that the static coefficient of friction should be at least 0.5 for all walkway surfaces under both wet and dry conditions [1].

TABLE 17 - EXPERIMENTAL RESULTS OF DRY AND WET TRIALS FOR FRICTION TEST

Test Type	**Shoe Type**	**Trial 1**	**Trial 2**	**Trial 3**	**Average Angle**	μ_S
Dry	*Boot*	50°	50°	50°	50°	1.19
	Running shoe	53°	50°	52°	51.7°	1.27
	Sandal	42°	40°	42°	41.3°	0.88
	Indoor slipper	40°	40°	40°	40°	0.84
Wet	*Boot*	60°	60°	60°	60°	1.73
	Running shoe	45°	60°	38°	47.7°	1.10
	Sandal	70°	80°	70°	73.3°	3.33
	Indoor slipper	20°	30°	50°	33.3°	0.66

0.60-0.80	0.80-1.00	1.00 and up

As is evident in the table, every trial yielded a coefficient of static friction that beyond exceeds the recommended value for walkway safety, and a vast majority of the trials yielded a value that exceeded 1.0. It was also significant to recognize that although some values were highlighted in red/yellow, they still exceed the recommended value. The values were only differentiated using this colour-coded scale to bring attention that some footwear did indeed provide less traction on the sidewalk; however, it is still sufficient. Additionally, the shoes that had a lower amount of friction (the sandal and indoor slipper) are rarely worn by individuals during the winter.

The discrepancies in the angles for the “wet” test were explained by the fact that the amounts of snow and water added to the rubber surface varied slightly each time and were not precisely measured. However, each individual angle was greater than what was expected in terms of the safety aspect. It was also important to mention that the angle at which water easily flows off the mat was measured to be approximately < 10°, and if a “slanted” design were to be considered or implemented in the future (specifically to drain the water), it would still be safe to assume that slipping would not occur.

From this test, the conclusion is made that the safety performance of the material to be used for the modular sidewalk pieces is exceptional.

7 Conclusions and Recommendations for Future Work

Following the end of this design project, the student team obtained valuable information regarding each of the subsystems included in the final design: modularity, repairability, heating, stability, storability, and surface. This data primarily includes test results (focused and comprehensive) of various components and the student team's verdict regarding their overall effectiveness as part of the completed design. A summary of these conclusions is provided below for each subsystem:

The student team discovered that there are minor blockage issues when sliding the interlocking lips together. The modular sections will be upscaled to match the size of the sidewalk or walkway in which they will be deployed. In doing so, the modular components of the mat must be tested again for the potential blocking issue. If the same problem appears, the interlocking lips should be manufactured as one piece instead of gluing together individual laser-cut pieces. Furthermore, when the ramp is manufactured in a full size, it should be designed to leave space in the middle for the heating cable to protrude. The ramp should also be made in two different styles: one which connects to the upper interlocking lip and one which connects to the lower interlocking lip. In addition, a cap must be designed to cover the electrical connections within the recessed portion of the interlocking mechanism to prevent water damage to the heating cable.

Certain conclusions can be drawn regarding the repairability of the FLAB Mat. The overall concept worked as intended, giving access to the heating cable inside the mat. Some recommendations for this subsystem would be the use of a higher-quality separating zipper to allow the top layer of the mat to be completely separated; ensuring the zipper is mounted to a smooth rubber surface so as to not interfere with the zipping aspect of the zipper; and an improvement of the material surrounding the grommets, since the rubber deteriorates each time the grommets are removed.

The student team found that the FLAB Mat's melting rate is slightly undesirable. Moving forward, 1.5" spacing should be used instead of 2", and the 1/8" top-layer of rubber should be used instead of the 1/4" thick piece currently being used. Any further iterations of the FLAB Mat would have to utilize a heating cable that is longer and can reach more areas of the mat. Different cable layout patterns would have to be considered for later designs. Lastly, electrical modularity should be incorporated more into future designs that use a self-regulating heating cable. The temperature probe currently used in the FLAB Mat interferes with electrical modularity. A self-regulating heating cable would contain a plug at either end that allows for electrical modularity. Using these recommendations as a guide, the heating aspect of the FLAB Mat could be greatly improved.

Furthermore, the concrete anchors used for securing the mat outside performed exceptionally well in the limited testing conducted on the product. Even though the FLAB Mat was only screwed into soil, it resisted mild lateral forces and kept the surface stable until it was dislodged by a kick. Likewise, the installed grommets worked as intended by guiding the screws straight through the mat and into the ground below, thus keeping the surface flat. To improve upon the stability subsystem, the student team recommends that the mat be tested into concrete to verify its effectiveness and longevity. Additionally, varying screw lengths can be analyzed to determine the required depth for the anchors to provide sufficient stability.

Moreover, the storability of the mat is discovered to be excellent since it does not require any sort of straps to secure a bundle of mat when stacked. Also, the FLAB Mat stacks easily because the surface is

flat. The rubber surface provides enough friction to prevent sliding. If desired, straps may be explored in the future if the mat is manufactured in bulk but are not currently recommended.

The rubber surface chosen for the FLAB Mat was an excellent choice. It offered water-resistance, traction, heat retention, and the black colour absorbed radiation from the sun in the form of heat. The only concern with water resistance was the side flaps as during testing, these became damper than the student team would have liked. Different materials will have to be explored for these flaps in future designs.

The ability to easily control a heated sidewalk was not thoroughly explored in the FLAB Mat. Moving forward, some ideas for this could include using an on/off switch, having Arduino based sensors and controls, external control through mobile applications, or any combination of these three.

8 Afterword from "Fio and the Zoomers"

Fiorelli: I just wanted to say how much of an amazing experience it was working on this project with the rest of my teammates. We had a great team dynamic and that allowed us to mesh well with one another and cater to our strengths. I am also specifically thankful for the assistance and motivation that our TA and PM, Gokhan and Habib, provided during our design process as it made the overall process much easier. Regardless of how our product is perceived by others, I can confidently say that this project was a resounding success.

Leo: Thanks for being our TA and PM, Gokhan and Habib. They are the best TA and PM I've ever had. I have never seen a TA and PM as passionate as them. Every lab was really fun just because they were there. I'm glad to see them in person in the future after the pandemic.

Ben: Beginning this course, I was skeptical of the idea of having to create a design project over the course of the entire semester. The amount of work involved and the fact that there were multiple public presentations really worried me. However, as the semester progressed, our team was continually able to work through every problem that was thrown our way. I was so glad to be a part of a team that not only did the work and did it well but were also just great people to spend time with. Our team was not alone in our efforts, I wanted to especially thank our TA, Gokhan, and our PM, Habib. You guys made the weekly labs so much fun to attend. And your general happy attitude towards life was infectious. I am so proud of the product my teammates and I were able to create in just four short months. I hope that all my future project teams are as enjoyable to be a part of as this one.

Aliyaah: On the first day of this course, I looked at what this project entailed and almost changed my entire career path on the spot. It was terrifying and seemingly impossible, but it also turned out to be the most rewarding project I've ever had the opportunity to work on. The moment I was able to see a working prototype finally come to life from those simple, rough sketches we'd made was the moment I knew it had all been worth it. In the end, I am extremely proud of what we have created. I'm grateful for each one of my team members and what they were able to uniquely contribute to the project. But above all, I'm thankful for their hospitality, kindness, and friendship. To Habib and Gokhan, you guys are spectacular. Thank you for tolerating our weekly madness. Maybe I won't drop out of engineering after all.

FIGURE 27 - TEAM PHOTO

FIGURE 28 - FOOT PIC

9 Bibliography

[1] Global Floor Safety Network, "Coefficient of Friction," Global Floor Safety Network, [Online]. Available: https://gfsngroup.com/coefficient-friction/. [Accessed 11 April 2021].

APPENDICES

APPENDIX I: Design Files

TABLE 18 - DESIGN FILES

Document Name	Document Location and/or URL	Issuance Date
Final Print4.svg	https://makerepo.com/BenSpencer/819.flab-mat	March 2021
J-piece Good5.svg	https://makerepo.com/BenSpencer/819.flab-mat	March 2021
Ramp2.svg	https://makerepo.com/BenSpencer/819.flab-mat	March 2021
Rods.svg	https://makerepo.com/BenSpencer/819.flab-mat	March 2021
TopBottomFinal2.svg	https://makerepo.com/BenSpencer/819.flab-mat	March 2021

All the files in Table 18 were used in the construction of the modularity subsystem of the final prototype. Section 6.1.3 contains these same sketches with measurements. They are listed here in the original file format (.svg) for reference.

APPENDIX II: Client Needs Identification Table

Question	Customer Statement	Interpreted Need
Wants/Likes:	We would like the product to be removed and stored in the summer	The HS is removable, and storable
	We want the product to be moved by people	The HS is light and can be manipulated by hand easily
	We would like something that can withstand winter elements	The HS is rugged and durable
	We would like something that can be easily cleaned	The HS is cleanable
	We would like something that can be easily maintained	The HS is fixable/maintainable by uOttawa employees
	We would like something that is safe	The HS is safe
	We would like something that is economical to produce	The HS is cost effective
	We want something that can be turned off	The HS is controllable
What is Not Wanted/Dislikes:	We don't want people to fall	The HS provides traction
	We don't want people to fall	The HS is not a tripping hazard
	We don't want people to fall	The HS is immovable once placed
	We will be using opportunistic storage	The HS is compact in size when stored
	We don't like HSs that are permanent (heating elements within concrete)	The HS is removable
University Specifications:	The university has access to electricity and hot water	The HS can be integrated into university infrastructure
	Some areas of campus will require differently sized options	The HS is scalable and modular

APPENDIX III: Development of Design Criteria and Categorization

Prioritization	Interpreted Need	Design Criteria
5	The HS is removable	Weight (lbs.), Modular
3	The HS is light and can be manipulated by hand easily	Weight (lbs.)
3	The HS is rugged and durable	Material, Product life
3	The HS is cleanable	Material, Surface roughness
3	The HS is fixable/maintainable by uOttawa employees	Repair time (days), Minimal custom parts
5	The HS is safe	Flame resistant, Safe to the touch
4	The HS is cost effective	Cost ($)
4	The HS is controllable	Adjustable power
5	The HS provides traction	Material, Surface roughness
5	The HS is not a tripping hazard	Deployed height/Thickness (in)
4	The HS is immovable once placed	Displacement when deployed (in)
3	The HS is compact in size when stored	Collapsed volume (in^3)
5	The HS is storable	Collapsed volume (in^3)
4	The HS can be integrated into university infrastructure	Integrability
5	The HS is scalable and modular	Modularity

Functional Requirements	Constraints	Non-Functional Requirements
Modular	Collapsed Volume (in^3)	Product Life
Adjustable power	Weight (lbs.)	Minimal custom parts
Material	Cost ($)	Repair Time (days)
Surface Roughness	Deployed Height/Thickness (in)	Flame resistant
Integrability	Displacement when deployed (in)	Safe to the touch
	Operating Temperature (˚C)	

APPENDIX IV: Technical Benchmarking of Existing Products

Legend:		Green = 4	Yellow = 3	Orange = 2	Red = 1
Company / **Specification**	**Weighted Importance**	**Canada Mats**	**HeatTrak**	**Powerblanket**	**WarmlyYours**
Cost (CAD)	-	$680.99	$503.67	$725.54	$459.18 + $700 installation fee
Dimensions	-	3’ x 5’	2’ x 5’	3’ x 5’	3’ x 10’
Cost per unit area (CAD)	5	$45.4/ft^2	$50.4/ft^2	$48.4/ft^2	$15.3/ft^2
Weight	-	54 lbs	18 lbs	41 lbs	8.5 lbs
Weight per unit area	5	3.6 lbs/ft^2	1.8 lbs/ft^2	2.7lbs/ft^2	0.28 lbs/ft^2
Electrical requirements	2	120/240 Volt	120/208/240 Volt	120 Volt	120/240 Volt
Material	3	UV protected rubber	Customized thermoplastic, flame retardant	Industrial grade rubber with a vinyl shell	Polypropylene mesh with corrosion-resistant twin-conductor
Control	4	Automatic thermostats.	Manually powered, fixed temperature.	Automatic thermostats.	Timer control, automatic thermostats, remote control (additional cost).
Total:		44	48	45	65